

# Fault Feature Extraction Method of Rotor Vibration Signals Based on Blind Source Separation and Wavelet Transform

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**Abstract:** In this paper, a new fault feature extraction method is presented based on wavelet transform and blind source separation. At first, wavelet transform is employed to de-noise measured signals to remove the process noise. Then blind source separation based on second order statistics is used to extract blind source signals of the process. The simulation and experiment testing results show the proposed method that compare with other method based on blind source analysis directly with process information can effectively extract the quantitative feature extraction. Finally, the signals of rotor vibration with noise interference were separated successfully using the proposed method.

## 1 INTRODUCTION

Blind source separation (BSS) means that the observation signal can be used to recover the independent component process of the source signal according to the statistical characteristics of the input source signal without knowing the source signal and the transmission channel parameters. In recent years, BBS has become a very popular signal processing technology. Since Zeng and Li(2002, 2003) proposed a class method of neural blind source separation, the blind source signal separation method has made a number of fruitful research, in the field of communications, voice and biomedical rapid development and promotion.

The vibration signal of the mechanical equipment is an important information source for fault identification and diagnosis, and the vibration signal is often mixed with several signals, which brings difficulties to the feature recognition and diagnosis. The study of blind source signal separation method provides the conditions for the separation of vibration signals and fault feature recognition. In the mechanical fault diagnosis system, the signal obtained by the sensor is inevitably disturbed by different types of unknown noise. In the unknown general noise environment, the separation effect of BSS-based mechanical source signal is often poor if the influence of noise is

neglected (Miao, 2014; Lei, 2011; Hu, 2003; Yu, 2005). Therefore, the influence of noise must be taken into account in BSS-based mechanical fault diagnosis. In this paper, combined with wavelet filtering and BSS, the wavelet filter is used to de-noise the test signal, and then the second order statistic of the signal is used to separate the blind source signal, and the simulation and experimental study are carried out.

## 2 THE LIKELIHOOD OF THE BSS MODEL WITH NOISE MIXING

In the model of linear instantaneous mixing with noise, the relationship between the unknown source signal and the observed signal can be described as the form (Huang, 2008; Ye, 2010) of the equation (1)

$$y(t) = As(t) + n(t) \quad (1)$$

Where  $y(t) = [y_1(t), y_2(t), \dots, y_M(t)]^T$  is the M-dimensional random observation vector in the case of noise,  $s(t) = [s_1(t), s_2(t), \dots, s_N(t)]^T$  is the N-dimensional source signal, the components

$s_i(t)$  in the source signal are assumed to be statistically independent,  $n(t) = [n_1(t), n_2(t), \dots, n_M(t)]^T$  is the  $M$ -dimensional additive observation noise, and  $M \geq N$ ,  $A$  is a mixed matrix of an unknown  $M \times N$ . In this case, the purpose of blind source separation is to find an  $M \times N$  full rank separation matrix  $B$ , so that the estimated source signal vector between the various components as independent as possible, such as Figure 1 shows. In the figure, the output signal  $s'(t)$  is the estimation result of the source signal  $s(t)$ . It is defined as

$$s'(t) = By(t) = BA s(t) + Bn(t) \tag{2}$$

Obviously, if the noise item  $n(t)$  in equation (2) is not Gaussian noise, then its appearance makes the estimation of separation matrix  $B$  become a biased estimate.

However, even if  $B$  obtains an exact estimate of  $S$ , the  $Bn(t)$  in Eq. (2) also increases the variance of the source estimate  $S$ . Therefore, in the strong noise environment, if you want to improve the separation performance, the first need for effective de-noising method for signal de-noising.

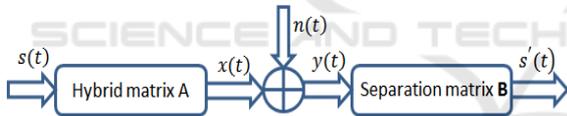


Fig.1 Model of blind source separation with noise

### 3 THE METHOD OF BLIND SOURCE SEPARATION BASED ON WAVELET

#### 3.1 The principle of wavelet de-noising

Wavelet transform can simultaneously analyze the local characteristics of the signal in the time domain and frequency domain. The continuous wavelet transform of the square integrable function  $f(t) \in L^2(R)$  is defined as (Li, 2005)

$$WT_f(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(t) \psi\left(\frac{t-b}{a}\right) dt$$

$$= \langle f(t), \psi_{a,b}(t) \rangle$$

The kernel function  $\psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right)$  of the wavelet transform is the result of the time shift  $\psi(t)$  and scale scaling  $b$  of the parent wavelet  $a$ , and  $\langle, \rangle$  is the inner product operation. The basic idea of wavelet transform is to use a family of functions to represent or approximate a signal. The family function is called the wavelet function system. It is through a wavelet function of the expansion and translation, to produce its "wavelet" to form.

#### 3.2 The method of blind source separation based on wavelet

In BSS-based mechanical fault diagnosis, people often on the test signal directly blind source signal separation, while ignoring the impact of noise, the separation effect is often poor (Miao, 2014). In order to eliminate the pollution of the noise signal and improve the effect of the blind source separation method, before the separation of the mixed signal vector  $y(t) = [y_1(t), y_2(t), \dots, y_M(t)]^T$  observed in the noisy case, it is necessary to de-noise with the wavelet method and then blind source signal separation. For wavelet de-noising - BSS method. This process can be expressed as Figure 2.

In this method, there are two important processes: wavelet de-noising pretreatment, blind source separation process. In (Li, 2005), these wavelet de-noising methods are compared. The corresponding wavelet de-noising method can be selected according to need. Here the wavelet soft threshold de-noising method for pre-processing.

For the blind source separation process, at present, there are many effective linear or nonlinear BSS algorithms, such as JADE, Infomax, MISEP, FastICA algorithm. Since the JADE algorithm (Huang, 2008) is robust and usually obtains a more stable source estimation result, the JADE algorithm is chosen.

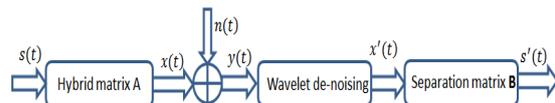


Fig.2 Wavelet de-noising-BSS method

## 4 SIMULATIONS AND EXPERIMENTAL RESULTS

### 4.1 Simulation

Using matlab to generate two simulation signals, as shown in Figure 3; the mixed matrix is randomly selected to obtain its mixed signal, and two separate signals are obtained by BBS separation without adding noise, as shown in Fig4. The separation results may also vary in amplitude and order due to the possibility of proportional distortion and order reversal in the matrix of weights used in the separation. It can be seen in Figure 4, the separation signal sequence and the source signal is consistent, the separation signal to retain the dynamic characteristics of the source signal, but in varying degrees of varying degrees of amplification.

However, this is the result of the ideal without noise or noise pollution is very small case. But in reality the impact of noise is inevitable, then the effect of the classic BBS method will be affected. In the observation signal to add a certain degree of white noise, and then BBS separation, separation of signals and shown in Figure 5, the separation signal and the original signal is very different, the separation effect is poor.

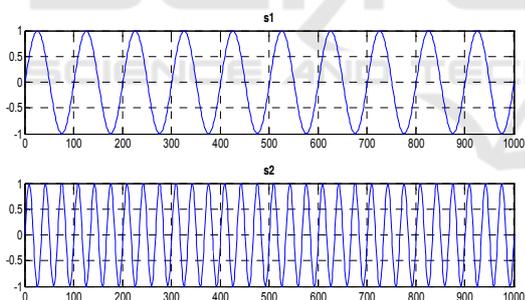


Fig.3 Original signals

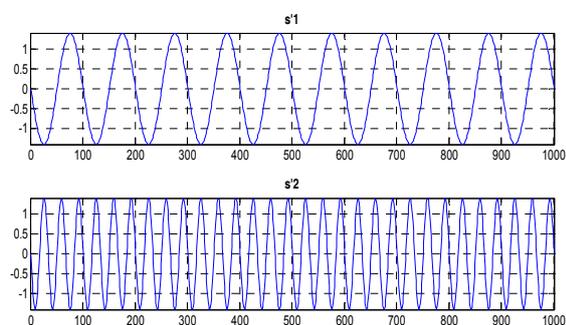


Fig.4 Separated signals in non-noisy mixtures

Therefore, characteristic signal separation in case of noisy interference, we must consider the impact of noise. Here the wavelet de-noising-BSS method is used, in which the de-noising step uses soft threshold wavelet de-noising, and the separation result is shown in Fig6. It can be seen that although there are some errors in the separation effect, the overall separation effect is still ideal.

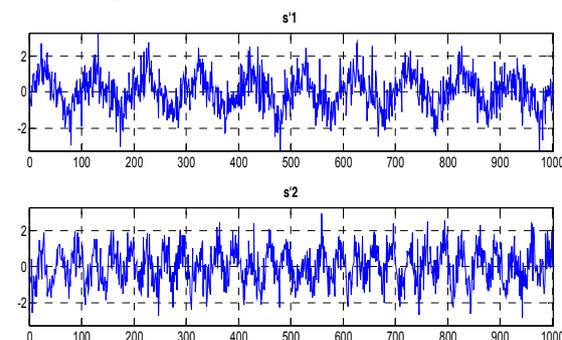


Fig.5 Separated signals in noisy mixtures (no de-noising process)

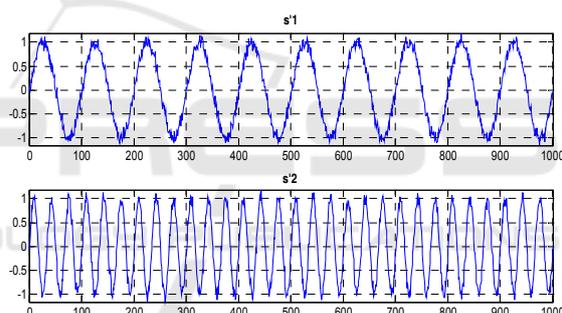


Fig.6 Separated signals in noisy mixtures (P.S.-soft shrinkage)

### 4.2 Experimental analysis

The test rotor system is shown in Fig7. For the set test system, two sensors are provided: an eddy current sensor 9 is mounted in the vertical direction of the mass disk I; a non-contact eddy current displacement sensor 10 is mounted in the vertical direction of the right side of the coupling. Rotor speed of 3800r / min, sampling frequency of 5kHz, sampling points of 1024. Signal acquisition and recording using a computer-based dynamic signal acquisition and analysis system.

Figure 8 is the noise source signal without noise separation, and Figure 9 is the vibration source signal separated by noise reduction. Corresponding to Fig. 8 and Fig. 9, it can be seen that the combination of wavelet de-noising and blind source separation can separate the vibrating source well.

Specific analysis of the results of the following aspects:

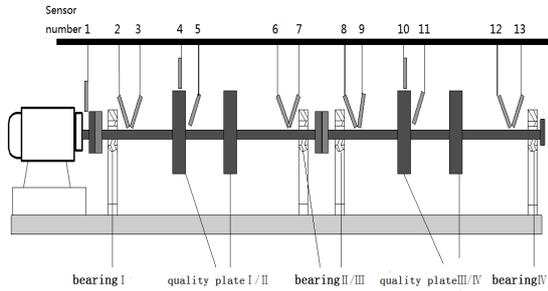


Fig.7 Rotor system and sensor position

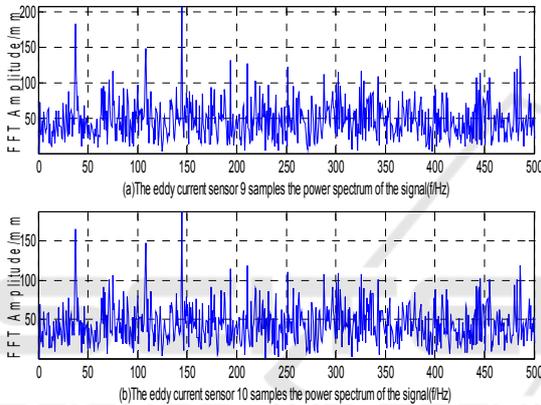


Fig.8 Power spectrums of mixed signals from two sensors

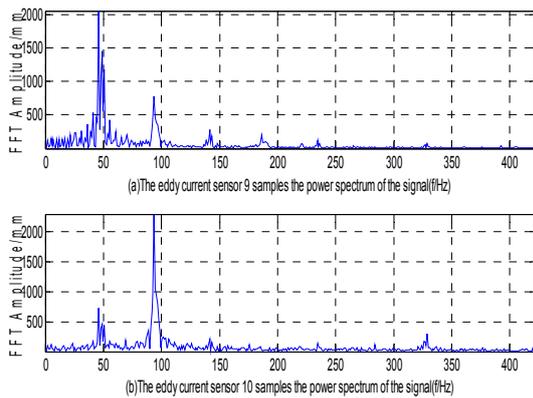


Fig.9 Power spectrums of vibration signals after separation

(1) From the spectrum of the two sensor acquisition signals in Fig. 8, it can be clearly seen that the non-stationary intrinsic vibration signal of the rotor is submerged in a number of impulsive

noise generated by the modulator in response to the frequency distribution of the rotor Band, the frequency distribution of the two stacked together. From the perspective of the strength of the signal component, the strong impulse noise occupies the main signal component status in the signal. Thus, the vibration signal is a mixed signal subjected to strong impulse noise and other random interference.

(2) It can also be seen in Fig. 8 that several fault characteristic frequencies of the acquisition signal are aliased on each power spectrum due to the propagation of the structural vibration, and it is difficult to determine which faults exist. It is difficult to accurately diagnose the fault in the event of an unknown failure.

(3) After the wavelet de-noising and blind source separation, the power spectrum shown in Fig. 9 is better separated from the fault characteristic. The power spectrum of each sensor signal after separation is basically only showing a fault feature. Figure 9 (a) shows only the rubbing characteristics, and Figure 9 (b) shows only the misalignment feature. Figure 9 (a) and Figure 9 (b), although both are multiplier, but Figure 9 (b) 2 times the frequency is significantly greater than 1 octave. This distinguishes between rupture and misalignment.

(4) The results of wavelet de-noising and blind source separation clearly eliminate the influence of strong impulse noise and other random interference signals in Fig.

## 5 CONCLUSIONS

In BSS-based mechanical source separation, the resulting measurement signal is often contaminated by process noise, the useful signal is buried in the noise. In this paper, we first use the wavelet function to de-noise the measurement signal, and then use the second-order statistics of the signal to separate the blind source signal. By simulation As a result, it can be seen that in the case of strong background noise mixing, the separation of the mechanical source signal without direct noise removal is often not well separated because the noise can also be regarded as a source signal. Finally, the proposed method is applied to the actual rotor vibration source separation, although there are some errors in the separation effect, but the overall separation effect is still ideal. Simulation and experimental results show that the blind source signal separation based on wavelet de-noising is more effective to extract the essential signal characteristics of rotor vibration fault than the direct blind source separation.

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## REFERENCES

- Z. Peng, Y. He, F. Chu, Vibration signal analysis and feature extraction based on reassigned wavelet scalogram, *Journal of Sound and Vibration* 253 (5) (2002) 1087-1100.
- Z.N. Li, Q.Q. Ding, Z.T. Wu, C.J. Feng, G.B. Yang, Blind system identification and fault diagnosis, *Journal of Zhejiang University (Engineering Science)* 37 (2) (2003) 215-220.
- Miao Feng, Zhao Rongzhen. Separating for nonlinear mixed rotor fault signals with violent pulse interferences. *Journal of Vibration, Measurement & Diagnosis*, (2014)34(4):625-630.
- Lei Yanbin, Li Shunming, Men Xiuhua et al. Separating mixed rotor vibration signals based on auto-correlation de-noising[J]. *Journal of Vibration and Shock*. (2011)30(1):218-222.
- J.S. Hu, Empirical mode decomposition time-frequency analysis method and experiment of fault diagnosis for rotating machinery, Ph.D. Thesis, Zhejiang University, 2003.
- D.J. Yu, J.S. Cheng, Y. Yu, Application of EMD method and Hilbert spectrum to the fault diagnosis of roller bearings. *Mechanical Systems and Signal Processing* 19 (2) (2005) 259-270.
- Li Yi, He Yongyong, Li Zhi nong et al. Study on application of blind source separation and wavelet denoising in rubbing fault acoustic signal analysis[J]. *Journal of Mechanical Strength*. 2005.27(6):719-724.
- HUANG Jin-ying, PAN Hong-xia, BI Shi-hua. Application of particle swarm optimization blind source separation technology in fault diagnosis of gearbox. *J. Cent. South Univ. Technol.* (2008) 15(s2): 409-415.
- Ye Hongxian, Yang Shixi, ang Jianxin. Mechanical vibration source number estimation based on EMD-SVD-BIC[J]. *Journal of Vibration, Measurement & Diagnosis*, 2010, 30(3):330-334.